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METHODS USED FOR THE ESTIMATION OF GAMMA DOSES IN AND AROUND A TOKAMAK REACTOR

C.F. Højerup

Abstract. Monte Carlo calculations of neutron flux in the NET reactor are described. The gamma sources from neutron capture reactions and from decays of radioactive nuclides are determined. A "reciprocity" approach is described, which in an approximate way, but with a reasonable calculational effort, allows an estimation of the gamma dose in selected points from all the distributed sources.

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1. CALCULATION OF NEUTRON FLUX

The NET-DN reactor has been modelled as a 1/32 segment with reflecting boundaries, Figs. 1 and 2.

The tori are replaced by cylinders, which simplifies the geometry.

The Monte Carlo code, MC ?2, has been used. The specification of the geometry has been made exclusively by stating that cells have a positive or negative sense with respect to the surfaces defined. In restricting oneself to this kind of geometry specification, it was fairly simple to write an auxiliary programme, VOLUME, which calculates the volumes of the cells. The latter is a necessary input for MCNP2, when dealing with flux tallies.

With a view to the subsequent activation calculations the energy structure was chosen to be the REAC-ECN 100 groups structure, table 1.

The neutron source was specified as a 14 MeV monoenergetic volume source shaped as a thin cylinder around the centre line of the torus.

Neutron importance were increased by a factor of 5 at each surface passed in the direction away from the source.

Despite that, some of the outer cells are so well shielded that the fluxes remain undetermined after some 10000 starting neutrons.

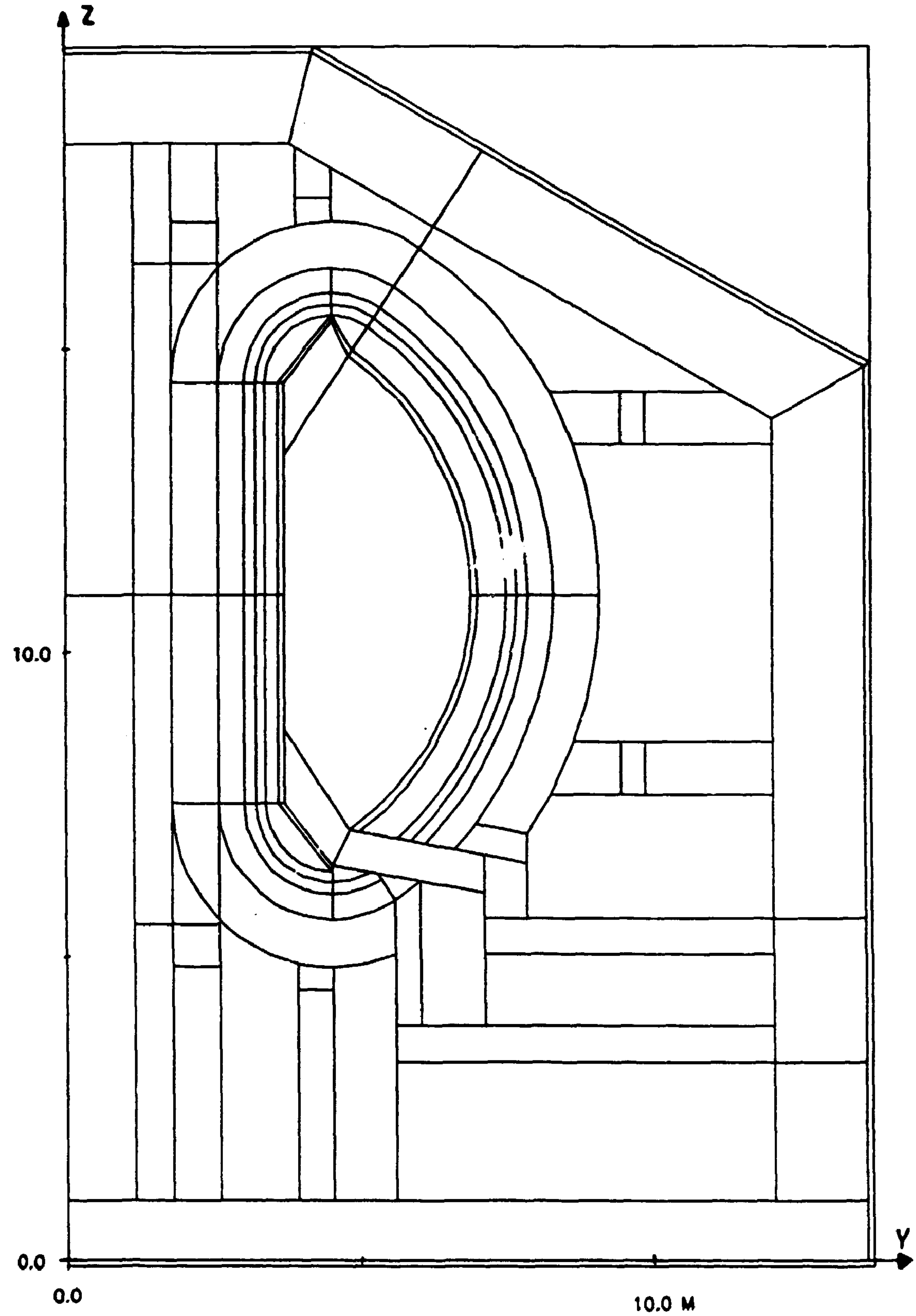
In Fig. 3 an example of the flux spectra obtained is shown. The 3 cells involved are from the inner part of the reactor, where the fluxes are well determined.

TABLE 1.

100 GROUP ENERGY STRUCTURE

UPPER ENERGIES(MEV):

GROUP	1	2	3	4	5
ENERGY	0.4140E-06	0.5316E-06	0.6826E-06	0.8764E-06	0.1125E-05
GROUP	6	7	8	9	10
ENERGY	0.1445E-05	0.1855E-05	0.2382E-05	0.3059E-05	0.3928E-05
GROUP	11	12	13	14	15
ENERGY	0.5044E-05	0.6476E-05	0.8315E-05	0.1068E-04	0.1371E-04
GROUP	16	17	18	19	20
ENERGY	0.1760E-04	0.2260E-04	0.2902E-04	0.3727E-04	0.4785E-04
GROUP	21	22	23	24	25
ENERGY	0.6144E-04	0.7889E-04	0.1013E-03	0.1301E-03	0.1670E-03
GROUP	26	27	28	29	30
ENERGY	0.2145E-03	0.2754E-03	0.3536E-03	0.4540E-03	0.5830E-03
GROUP	31	32	33	34	35
ENERGY	0.7485E-03	0.9611E-03	0.1234E-02	0.1585E-02	0.2035E-02
GROUP	36	37	38	39	40
ENERGY	0.2613E-02	0.3355E-02	0.4307E-02	0.5531E-02	0.7102E-02
GROUP	41	42	43	44	45
ENERGY	0.9119E-02	0.1171E-01	0.1503E-01	0.1931E-01	0.2479E-01
GROUP	46	47	48	49	50
ENERGY	0.3183E-01	0.4087E-01	0.5248E-01	0.6738E-01	0.8652E-01
GROUP	51	52	53	54	55
ENERGY	0.1111E+00	0.1228E+00	0.1357E+00	0.1500E+00	0.1657E+00
GROUP	56	57	58	59	60
ENERGY	0.1832E+00	0.2024E+00	0.2237E+00	0.2472E+00	0.2732E+00
GROUP	61	62	63	64	65
ENERGY	0.3020E+00	0.3337E+00	0.3683E+00	0.4076E+00	0.4505E+00
GROUP	66	67	68	69	70
ENERGY	0.4979E+00	0.5502E+00	0.6081E+00	0.6721E+00	0.7427E+00
GROUP	71	72	73	74	75
ENERGY	0.8209E+00	0.9072E+00	0.1003E+01	0.1108E+01	0.1225E+01
GROUP	76	77	78	79	80
ENERGY	0.1353E+01	0.1496E+01	0.1653E+01	0.1827E+01	0.2019E+01
GROUP	81	82	83	84	85
ENERGY	0.2231E+01	0.2466E+01	0.2725E+01	0.3012E+01	0.3329E+01
GROUP	86	87	88	89	90
ENERGY	0.3679E+01	0.4066E+01	0.4493E+01	0.4966E+01	0.5488E+01
GROUP	91	92	93	94	95
ENERGY	0.6065E+01	0.6703E+01	0.7408E+01	0.8187E+01	0.9048E+01
GROUP	96	97	98	99	100
ENERGY	0.1000E+02	0.1105E+02	0.1221E+02	0.1350E+02	0.1492E+02



F I G. 1

CROSS SECTIONAL VIEW OF NET-DN CONFIGURATION (Y-Z PLANE)

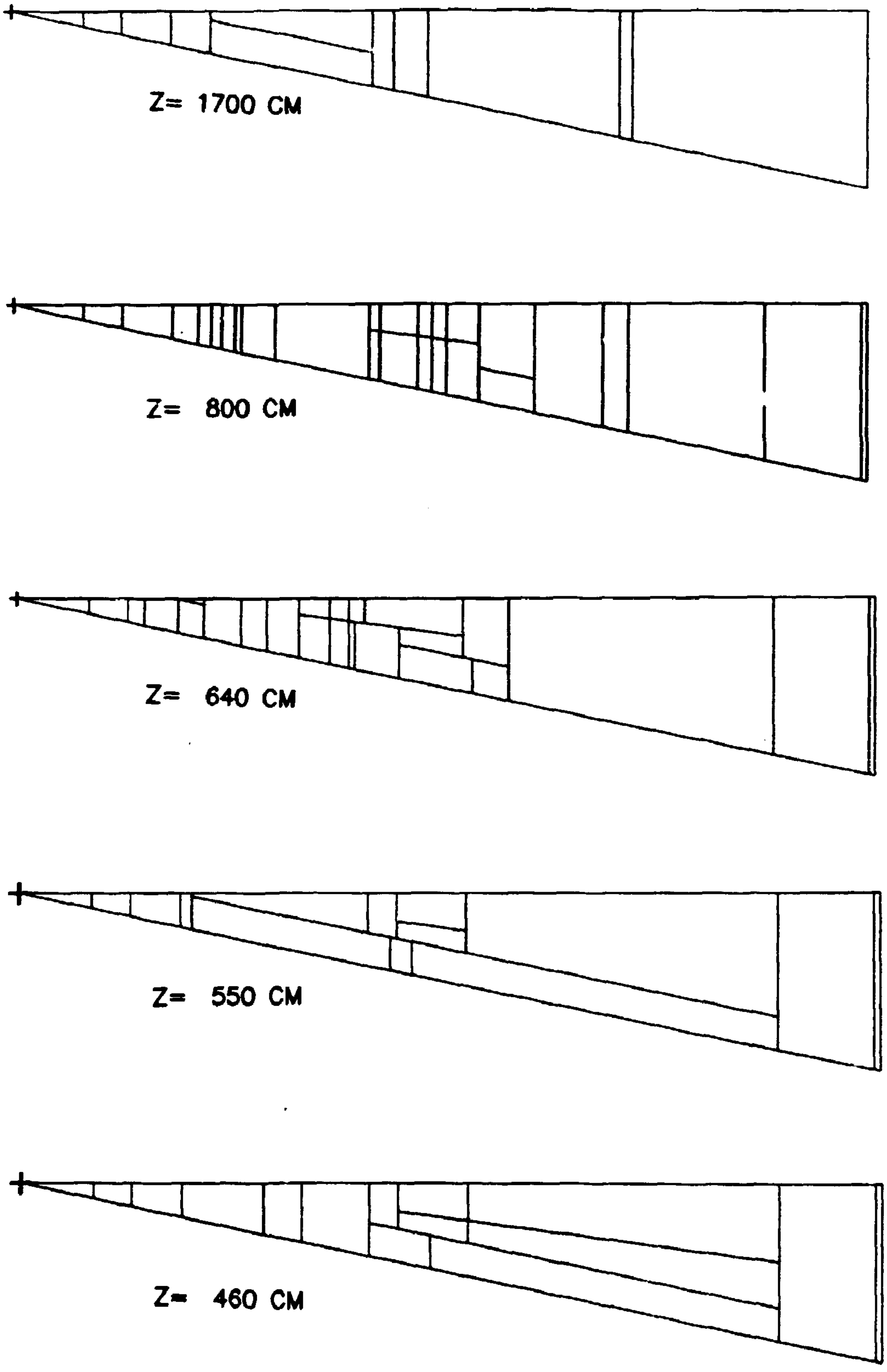


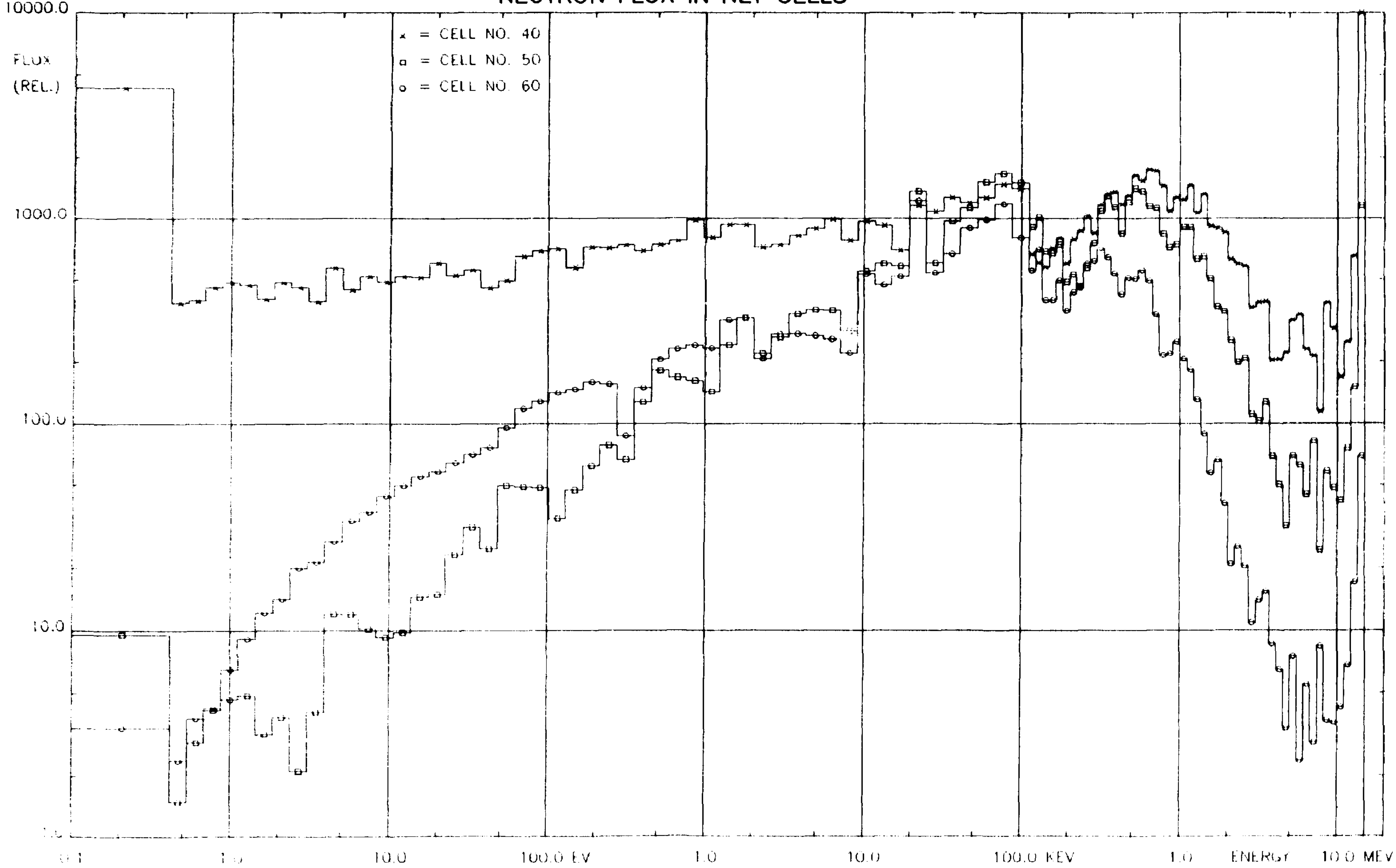
FIG. 2.

CROSS SECTIONAL VIEWS OF NET–DN CONFIGURATION

PLANES PARALLEL TO X–Y PLANE

FIG. 3

NEUTRON FLUX IN NET CELLS



2. MCNP2 CALCULATIONS OF GAMMA FLUX AND REMARKS ON "RECIPROCITY" APPROACH

If the gamma flux from activation products or from neutron captures is to be known in all points of the TOKAMAK, it implies an enormous amount of computations, namely the filling out of a matrix.

$$G'(g,i,g',i')$$

which stands for the gamma flux in (group g', cell no i') due to a unit source of 1 γ/s in (group g, cell no. i). Since the number of gamma groups must be in the order of 5-10 (6 are used in the present calculations) and the number of cells must be in the order of 50-200 (113 are used here), filling out of the full G'-matrix would require 250-2000 separate Monte Carlo calculations (each requiring about 1 million histories).

In this work another approach is used, which is approximate, but on the other hand only requires 6 MC runs:

The unit source 1 γ/s is placed in one point, namely that point, where the gamma flux is to be calculated, and the source-gamma is given successively the mean energy of group 1, 2, 3, 4, 5, and 6. This gives 6 MC calculations, each determining the gamma flux in all cells and all groups due to the unit sources, i.e., we get a matrix

$$G(g,g',i')$$

giving the gamma flux in (group g', cell i') from 1 γ/s in group g placed in the measuring point, M. If the TOKAMAK was an infinite, homogeneous medium, it is clear that the flux in (group g', cell i') from a unit source in (group g, point M) would be exactly the same as the flux in (group g', point M) from a unit source in (group g, cell i'), since all particle tracks can be reversed.

As the TOKAMAK is not an infinite, homogeneous medium this reciprocity theorem will not be exactly valid, but one might hope that it is sufficiently close to be satisfied to give useful results.

A test of the degree of "reciprocity" was performed with a two-dimensional neutron diffusion code, DIFF2D, on a problem with 3 energy groups and alternating layers of materials, imitating vacuum, SS, and concrete.

The geometry is shown in Fig. 4.

The source, 1 n/s in group 1, was placed in turn in the meshes A, B, C, D, and E. The resulting fluxes in the same meshes are listed in table 2.

If the reciprocity theorem was exactly satisfied, the matrix should be symmetrical with respect to the diagonal. The deviations are seen to be largest in the lowest group and close to the totally absorbing surface. In the interior the agreement is quite good.

Although the above procedure is not a complete test of the goodness of the reciprocity approach, it gives some confidence to the results obtained by using it.

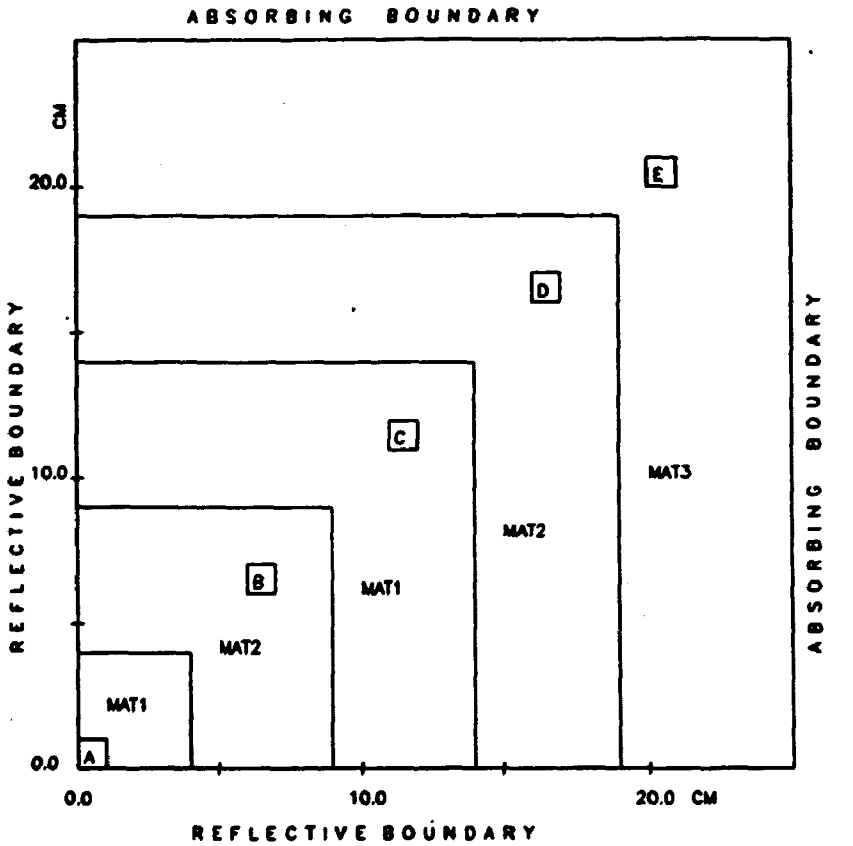
<u>Table 2</u>. Test of "reciprocity" theorem.
Fluxes in A, B, C, D, E (Fig. 4) from 1 n/s in group 1 (highest energy) placed successively in the same points.

Source in		A	B	C	D	E
Flux in						
	Group 1		$1.17_{10}{-1}$	$2.99_{10}{-2}$	$8.00_{10}{-4}$	$6.46_{10}{-6}$
A	- 2	-	$3.40_{10}{-1}$	$1.12_{10}{-1}$	$6.62_{10}{-3}$	$1.29_{10}{-4}$
	- 3		$6.72_{10}{-1}$	$2.73_{10}{-1}$	$3.01_{10}{-2}$	$1.24_{10}{-3}$
	Group 1	$1.17_{10}{-1}$		$1.69_{10}{-1}$	$4.45_{10}{-3}$	$3.59_{10}{-5}$
B	- 2	$3.40_{10}{-1}$	-	$2.95_{10}{-1}$	$2.25_{10}{-2}$	$4.87_{10}{-4}$
	- 3	$6.68_{10}{-1}$		$4.41_{10}{-1}$	$7.01_{10}{-2}$	$3.46_{10}{-3}$
	Group 1	$2.99_{10}{-2}$	$1.69_{10}{-1}$		$3.76_{10}{-2}$	$2.99_{10}{-4}$
C	- 2	$1.14_{10}{-1}$	$2.96_{10}{-1}$	-	$9.91_{10}{-2}$	$2.60_{10}{-3}$
	- 3	$2.89_{10}{-1}$	$4.51_{10}{-1}$		$1.79_{10}{-1}$	$1.20_{10}{-2}$
	Group 1	$8.00_{10}{-4}$	$4.45_{10}{-3}$	$3.76_{10}{-2}$		$1.93_{10}{-2}$
D	- 2	$6.69_{10}{-3}$	$2.26_{10}{-2}$	$1.01_{10}{-1}$	-	$7.94_{10}{-2}$
	- 3	$3.18_{10}{-2}$	$7.20_{10}{-2}$	$1.96_{10}{-1}$		$2.11_{10}{-1}$
	Group 1	$6.46_{10}{-6}$	$3.59_{10}{-5}$	$2.99_{10}{-4}$	$1.93_{10}{-2}$	
E	- 2	$1.86_{10}{-4}$	$6.84_{10}{-4}$	$3.54_{10}{-3}$	$9.60_{10}{-2}$	-
	- 3	$3.08_{10}{-3}$	$7.97_{10}{-3}$	$2.56_{10}{-2}$	$3.02_{10}{-1}$	

FIG. 4.

TEST OF 'RECIPROCITY' THEOREM

GEOMETRY USED IN 3-GROUP CALCULATION



MAT1 (VACUUM)	MAT2 (ST.ST.)	MAT3 (CONCR.)
1.000E+01 1.000E+01 1.000E+01	DIFFUSION COEFFICIENTS (CM): 1.369E+00 1.293E+00 0.915E+00	1.369E+00 1.293E+00 0.915E+00
1.000E-04 0.000E+00 0.000E+00 0.000E+00 1.000E-04 0.000E+00 0.000E+00 0.000E+00 1.000E-04	SCATTERING MATRICES (1/CM): 2.605E-02 0.000E+00 0.000E+00 2.598E-02 1.809E-02 0.000E+00 5.303E-08 1.702E-02 1.042E-02	4.000E-02 0.000E+00 0.000E+00 3.000E-02 2.000E-02 0.000E+00 5.000E-03 1.000E-02 5.000E-03

3. CALCULATION OF ACTIVATION PRODUCTS AND ASSOCIATED GAMMA EMISSIONS

By means of methods developed for burnup calculations in fission reactors and slightly modified as to the range of nuclides and the number of reactions, the intensity of neutron captures and the time variation of gamma-emitting radio nuclides can be calculated.

A F77 programme, ACTIVA, performs these calculations. Processes considered in the programme are:
Radioactive processes:

β^- (Meta-Meta, Meta-Ground, Ground-Meta, Ground-Ground)

β^+ (- - - - - - - -)

Radiative transition (Meta-Ground)

Neutron induced transformations:

1. NN
2. N2N
3. N3N
4. NNA
5. N2NA
6. NNP
7. NN2A
8. NND
9. NNT
10. NNH
11. NN2P
12. NG
13. NP
14. ND
15. NT

16. NH
17. NA
18. N2A
19. N2P

N = neutron
P = proton (H^1)
D = deuteron (H^2)
T = tritium (H^3)
H (He^3)
A = alpha (He^4)
G = gamma

A flow diagram for the ACTIVA programme is shown in Fig. 5.

It consists of a data administrating part, which reads input data from

- an input data file
- the MCNP2 neutron calculation result file
- the MCNP2 gamma calculation result files
- decay data for all nuclides considered
- decay gamma data for gamma emitting nuclides
- capture gamma data for most important nuclides
- neutron cross sections for all nuclides and all reactions considered

and the part performing the real calculations, cell by cell, at specified times and power levels. The results are gamma doses at the selected point corresponding to the specified times and power levels. Also, detailed inventories of radioactive nuclides in all parts of the TOKAMAK are obtained and may be used for considerations about handling and storage.

According to the degree of detail wanted, the output may become very voluminous.

A single page of results is shown in Fig. 6, giving the contributions to the dose rate from the various components of the TOKAMAK at a time shortly after shut down after a period of 1 year of full power operation. The contributions in each of the 6 gamma groups are given as well as the total.

F I G. 5.

FLOWDIAGRAM FOR THE ACTIVA PROGRAMME

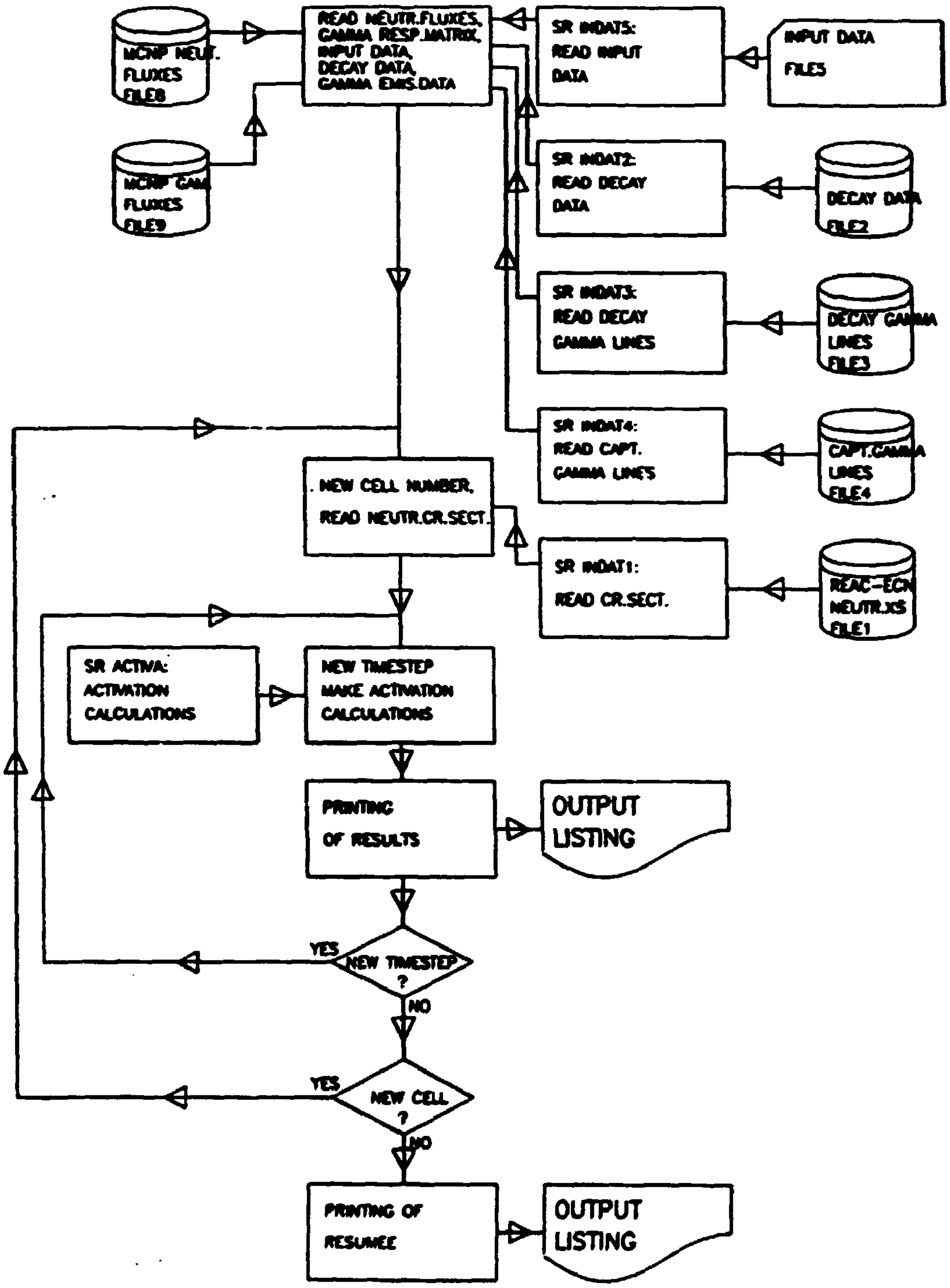


FIG. 6.

RESULTS FROM ACTIVA CALCULATIONS (SAMPLE)

TIME- 361.00 DAYS

FROM CELL	GROUP	1	2	3	4	5	6	TOTAL
10	PLASMA	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
40	FIRST WALL	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
50	VACUUM VESSEL	0.000E+00	0.000E+30	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
55	VACUUM VESSEL	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
60	TOR. FIELD COILS,INB	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
70	POL. FIELD COILS,INB	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
90	FIRST WALL	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
92	FIRST WALL	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
93	FIRST WALL	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
100	VACUUM VESSEL	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
102	VACUUM VESSEL	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
103	VACUUM VESSEL	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
105	VACUUM VESSEL	2.129E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.129E-04
110	TOR.FIELD COILS,TOP	3.300E-08	1.325E-32	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.300E-08
120	FIRST WALL	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
130	BREEDING BLANKET	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
140	FIRST WALL	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
150	VACUUM VESSEL	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
152	VACUUM VESSEL	2.006E-05	9.210E-05	1.860E-04	5.796E-07	6.320E-30	0.000E+00	2.909E-04
155	VACUUM VESSEL	9.041E-01	2.532E+00	2.520E-01	1.445E-03	1.064E-27	0.000E+00	3.769E+00
157	VACUUM VESSEL	2.979E+00	8.122E+00	5.372E-01	3.831E-03	2.173E-27	0.000E+00	1.164E+01
158	VACUUM VESSEL	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
160	TOR.FIELD COILS,OUTB	1.106E-04	1.273E-03	2.090E-04	3.345E-14	0.000E+00	0.000E+00	1.602E-03
163	EXHAUST PORT STRUCT.	8.107E-01	1.766E+00	5.247E-02	3.155E-04	1.851E-28	0.000E+00	2.629E+00
164	EXHAUST PORT STRUCT.	1.530E-01	2.993E-01	7.429E-02	2.247E-04	1.614E-28	0.000E+00	5.277E-01
165	EXHAUST PORT STRUCT.	3.595E-02	4.697E-02	3.526E-03	1.070E-05	6.005E-31	0.000E+00	8.647E-02
166	EXHAUST PORT STRUCT.	3.000E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.000E-04
167	EXHAUST PORT STRUCT.	7.761E-03	7.969E-05	8.568E-06	7.037E-08	1.221E-31	0.000E+00	7.849E-03
175	POL.FIELD COILS,TOP	2.234E-26	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.234E-26
198	POL.FIELD COILS,TOP	6.196E-14	0.000E+00	0.000E+30	0.000E+00	0.000E+00	0.000E+00	6.196E-14
220	POL.FIELD COILS,OUTB	2.405E-25	9.011E-25	5.202E-24	0.000E+00	0.000E+00	0.000E+00	6.351E-24
230	BIOL. SHIELD	4.406E-01	4.127E-01	6.600E-01	5.262E-01	5.061E-24	0.000E+00	2.086E+00
250	BIOL. SHIELD	2.709E-02	1.864E-02	2.612E-02	2.119E-02	2.350E-25	0.000E+00	9.304E-02
TOTAL		5.449E+00	1.320E+01	1.615E+00	5.532E-01	6.100E-24	0.000E+00	2.082E+01

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